

# Modern technologies of processing municipal solid waste: investing in the future

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**Abstract.** The problem of effective municipal solid waste (MSW) management is known to all the municipal entities of the Russian Federation. The problem is multifaceted and complex. The article analyzes the dynamics of municipal solid waste formation and its utilization within the territory of the EU and Russia. The authors of the paper suggest a project of a plant for processing municipal solid waste into a combustible gas with the help of high temperature pyrolysis. The main indicators of economic efficiency are calculated.

## 1. Introduction

The organization of effective waste production and consumption management is one of the most pressing environmental problems of the Russian Federation. The problem is connected with the organization of waste collection, generation, transportation, processing, recycling, waste disposal and neutralization. Among the aspects to be discussed are the following:

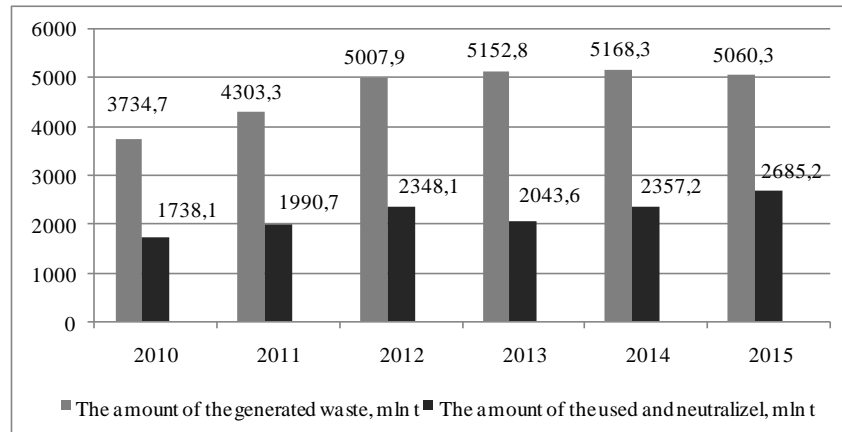
- 1) the need to solve the problems of dual nature related both with environmental protection and resource conservation issues, recycling and reuse of waste;
- 2) the steady increase of waste disposal, i.e. the need for constant removal of new land for waste storage and disposal, as well as the reclamation of disturbed (polluted, degraded) lands within the territories of closing landfills and waste dumps;
- 3) territorial specificity of the problem connected with the fact that the bulk of industrial waste generates in a relatively small number of regions, that is, within the locations of chemical, petrochemical, steel, pulp and paper and other industries and areas of mining. However, municipal solid waste [1], is formed everywhere, but at the same time it is utilized within the territory of the Russian Federation in a very uneven manner.

## 2. Analysis of the world and domestic trends in municipal solid waste treatment

The overall amount of production and consumption of waste, which has been collected and recorded within the territory of the Russian Federation by the end of 2015, reached the number of 31.5 billion tons [2]. The annual volume of production and consumption waste reached 5060.3 million tons in 2015. The share of used and neutralized waste was 53 %, which made 2685.2 million tons (Figure 1). In contrast, the volume of municipal solid waste reached 48.6 million tons and the volume of used and neutralized waste was only 7 % or 3.4 million tons. The dynamics

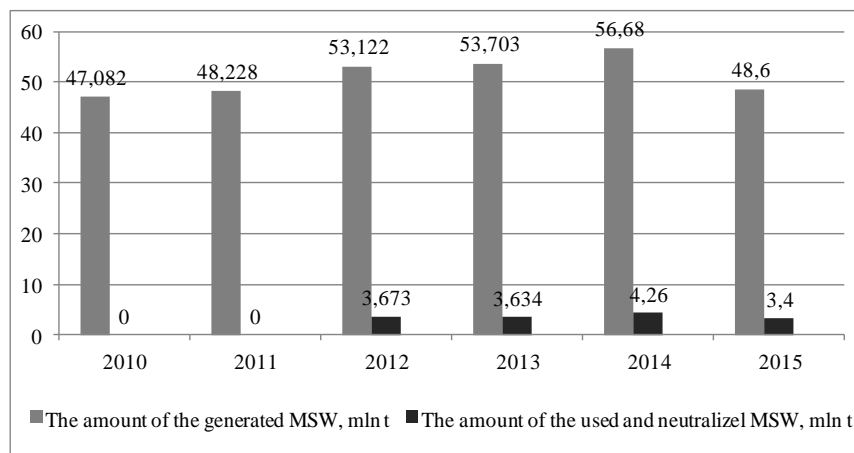


of formation and usage of production and consumption waste within the territory of the Russian Federation can be seen in Figures 1 and 2 [2–4].



**Figures 1.** The dynamics of formation and usage of production and consumption waste within the territory of the Russian Federation

The above statistics, to some extent, are estimates because it is hard to take into consideration all the waste generated decades ago; it is also difficult to identify all the previously accumulated waste from the point of its decomposition, dilution, weathering, corrosion, overgrown vegetation, and other processes.



**Figures 2.** The dynamics of formation and usage of production and consumption waste

Only a relatively small part of overall solid waste undergoes waste disposal, processing and incineration within the special facilities. Thus, in 2015 waste processing facilities received about 21 million m<sup>3</sup> of municipal solid waste (7 % of the total waste disposal volume), while waste incinerating facilities received less than 7 million m<sup>3</sup> of solid waste (about 2 %). It is important to remember that besides the municipal solid waste taken from the residential areas, there is waste liquid (42 million m<sup>3</sup>) and snow (62 million m<sup>3</sup>), which is contaminated with various harmful impurities trapped in during the winter period [2].

The comparison with some EU countries shows that the share of incinerated solid waste may reach up to 70 %. For example, in Switzerland it reaches 79 %, in Japan it makes up to 72 % (Table 1) [2]. The EU countries use the concept of municipal waste (MW), which makes it possible to pursue the objective international comparisons.

In many cases, the processes of solid waste removal and recycling have their own specifics in many large cities of Russia. There was a significant increase in the volume of solid waste removed in 2001–2015 period in most cities. However, the increase rates vary.

In 2015, several subjects of the Russian Federation started working with landfills of solid waste and waste-processing complex. Among them are the Republic of Adygea, Bashkortostan, Buryatia, Ingushetia, Karachay-Cherkessia, Komi, Mari El, Udmurtia and Chuvash Republic; Krasnodar, Perm, Stavropol and Khabarovsk territories; Belgorod, Bryansk, Vladimir, Vologda, Ivanovo, Kirov, Kostroma, Kurgan, Kursk, Lipetsk, Murmansk, Omsk, Oryol, Rostov, Samara, Saratov and Sakhalin, Smolensk, Tambov, Tula and Tyumen regions; St. Petersburg, Khanty-Mansi Autonomous District of Yugra [2].

**Table 1.** The Proportion of Incineration of Municipal Solid Waste in Developed Countries

Country	Population, mln.	Municipal Solid Waste, mln. tons	The Number of Waste Burning Plants	The share of Burning Waste, %
Switzerland	7	2,9	29	79
Japan	123	44.5	1900	72
Denmark	5	2.6	32	65
Sweden	9	2.7	21	59
France	56	18.5	100	41
Holland	15	71	9	39
Germany	61	40.5	51	33
Italy	58	15.6	51	17
USA	248	180	168	16
Spain	38	11.8	21	6
England	57	35	7	5
Russia	145	-	8	-

Table 2 contains the data (in the per capita of the country) on the dynamics of municipal waste formation and disposal in the landfills of the EU countries and Russia [2]. If to talk about the relevant trends in the United States, it should be said that its "trash market" is on the rise: there are about 550 waste recycling plants and about 56 thousand of waste collection and disposal enterprises there. According to the forecasts, the amount of solid waste sent for recycling can reach 30–55 % in this country in the coming years.

The analysis of EUROSTAT data [5] for the period from 2000 to 2014 shows that in many countries the volume of municipal waste dumping largely decreased – both in terms of the overall tonnage and per an inhabitant. In such countries as Belgium, Germany, the Netherlands and Sweden, the corresponding figures went down from 10 to 30 times. At the same time, there was no waste dumping carried out in Switzerland at all.

The USA reduced the waste of dumping in 2000–2012 (about 3–4 % percent).

**Table 2.** The Dynamics of Municipal Waste Formation and Disposal within the Landfills of the EU and the Russian Federation (1 kg per inhabitant)

Country	2005	2010	2012	2013	2014	2014 in % to 2000
The total of formed and disposed waste in 28 countries	521/-	503/185	485/154	477/143	475/132	91/-
Austria	580/196	562/18	579/25	578/23	565/23	97/12
Belgium	471/91	456/8	447/5	437/4	435/4	92/4.4
Bulgaria	612/400	554/411	460/318	432/298	442/307	72/77
Great Britain	577/468	509/234	477/177	482/164	482/134	82/29

Country	2005	2010	2012	2013	2014	2014 in % to 2000
Hungary	446/366	403/284	402/263	378/244	385/221	86/60
Germany	642/167	602/3	619/1	609/8	618/9	96/5.4
Denmark	610/66	673/23	750/16	752/13	759/10	124/15
Spain	658/337	510/318	468/284	454/253	435/240	66/71
Italy	509/385	547/253	504/468	491/181	488/154	96/40
Netherlands	598/57	571/9	549/8	526/8	527/8	88/14
Poland	320/313	316/195	317/198	297/157	272/143	85/46
Romania	355/295	313/238	252/171	254/175	-/-	72/59
Finland	502/305	470/212	506/166	493/144	482/124	86/28
France	514/219	533/166	523/139	517/134	511/132	99/60
Sweden	428/97	439/4	450/3	451/3	438/3	102/3.1
Switzerland	656/54	708/-	694/-	702/-	730/-	111/-
Russia, take out Municipal Solid Waste	207	330	371	347	389	188

As for Russia, there was an increase in the volume of solid waste disposal. If we compare solid waste disposal management in the EU, the USA and Russia, it becomes obvious that Russia needs serious work to be done regarding a number of indicators. In 2014–2015 the government of the country undertook legislative, organizational, administrative, fiscal, economic and other measures intended to provide a specific reserve for the further development and increase of efficiency of production and consumption waste, including the scope of the MSW. One of the most urgent question is the creation of a modern infrastructure for the processing (recycling) of various waste to produce secondary (recurrent) and/or by-products [2].

### 3. Modern methods of processing municipal solid waste

Although there is a variety of methods processing municipal solid waste, there is some generally accepted classification of technologies. Among the basic methods are: 1) deposition of landfilled solid waste; 2) sorting; 3) mechanical biorefining; 4) direct combustion; 5) anaerobic fermentation and composting; 6) pyrolysis and gasification.

It should be noted that there are no universally accepted standards or regulations to strictly specify or apply the above-mentioned methods. Waste processing issues are addressed in different ways in different countries, regions, cities and towns. Much depends on the local conditions, financial possibilities and other factors. Therefore, each case is to be treated individually depending on the goals and objectives to be achieved. The authors of the paper have not determined any particular solution to the problem of solid waste processing in Ekaterinburg.

In this paper, the authors discuss pyrolysis as a highly effective way of waste recycling and disposal. It helps to make the process of waste processing useful in terms of its transformation into heat or electrical energy. Besides it helps to significantly lower pollutant emissions, which are a way higher than in the normal combustion in the incinerator. It is necessary to partially or fully prepare waste for the process of pyrolysis.

The pyrolysis process includes the following stages:

- drying up to a certain moisture degree;
- pyrolysis process itself;
- gasification.

The following components are formed in the pyrolysis process: synthesis gas, resins, water vapor, solid carbon residue, which can also be called coke. Pyrolysis is a process of decomposition of the substance into simpler components, which is implemented under high temperatures stress with the lack of air. During gasification process the solid residue transforms into gas under the influence of atmospheric oxygen or steam [6]. The inorganic residue received after the gasification should be

disposed in a special landfill. However, the overall proportion of such residues does not exceed 10 % of the original mass of the overall load.

The process can be divided into three types in accordance with the pyrolysis temperature of [6, 7]

- low-temperature pyrolysis presupposes the temperature of 450–500 °C. The solid waste is said to release the least of gas, the maximum number of different oils, tars or resins and solid residue;
- medium temperature pyrolysis has the temperature up to 800 °C. This type of pyrolysis is known for the increase in the gas generation and the volume of resins, oils and reduced residue;
- high temperature pyrolysis implies temperatures above 800 °C. During the high-temperature pyrolysis gases are generated to the maximum degree; formation of resins, oils and solid is minimal. High temperature pyrolysis is limited by 1050–1100 °C, since this temperature range is connected with the process of melting residues – slag, which subsequently complicates the work of slag removal system.

The pyrolysis process includes four successive stages:

- waste sorting and selection of metals and the subjects above the allowable size. This procedure is carried out with the help of electromagnets and induction separation;
- gasification process, which is aimed to generate synthesis gas, slag;
- cleaning of synthesis gas in a scrubber with an alkaline solution of sulfur, fluorine, chlorine, cyanide;
- burning of purified synthesis gas in the waste heat boiler in order to produce electricity and heat.

This method of processing of municipal solid waste is environmentally friendly and promising to date. The resulting syngas can be effectively used. High temperatures help to decompose harmful substances. The sorting process helps to select metal, which may also be reused.

High-temperature pyrolysis is a cost-effective, environmentally sound and technically feasible way to dispose municipal solid waste without any substantial preparation, sorting, drying, since there are no stringent requirements to the stock (which means that even unsorted garbage can be disposed).

The process of high temperature pyrolysis efficiency reaches up to 95 %. It means that it is possible to process little combustible wastes with up to 90 % ash content and a high humidity of 60 % to [6, 7].

Advantages of high-temperature pyrolysis are as follows:

- High temperature pyrolysis allows to process high ash and the wet components;
- Exhaust gases are generated with the low solids content, as they have to undergo a kind of a filter through the raw material layer. This helps to reduce costs for the purchase of gas treatment plants, such as cyclone filters;
- The process is connected with the generation of valuable synthesis gas that can be used to generate heat and electricity;
- High temperature pyrolysis forms slag, which can be used in the construction industry;
- There is a garbage sorting process, which helps to select non-ferrous and ferrous metals, available-for-sale.

Thus, the usage of this technology can completely change the current approach in the field of waste management and significantly reduce the amounts of waste location and begin to effectively process and use municipal solid waste.

#### **4. Feasibility study of the project for the processing of municipal solid waste with the help of high-temperature pyrolysis in Ekaterinburg**

Ekaterinburg is a large city with the population over 1.5 million people. A human being produces about three kilograms of waste daily or about a ton of waste yearly. Every year the city processes and recycles more than half of human waste. The municipal economic entity Ekaterinburg was founded in 2015 1150.02 ths. Tons of waste (0.64 % of the total waste generation by region as a whole). The municipal solid waste amounted to about 446.2 thousand tons. Waste recycling and disposal amounted to 578.77 thousand tons, which is 50.3 % of the total waste generated in the municipal entity, and 0.69 % of the volume of waste and disposal waste in the whole region.

In 2015 Ekaterinburg Municipal Unitary Enterprise Specialized Depot delivered about 109.1 thousand tons of municipal solid waste (in 2014 – 116.2 thousand tons) to Shirokorechensky Waste Sorting Complex of Solid Waste Landfill. Waste sorting averaged 6.6 % (in 2014 – 8.7 %; in 2013 – 11.7 %) [8].

It is obvious that the city of Ekaterinburg faces quite a challenge in the sphere of municipal solid waste management. The reform in the sphere of municipal solid waste management requires the improvement of mechanisms and methods of municipal solid waste management within the territory of Ekaterinburg municipal entity [9].

The undertaken research helped to work out a pilot project, which has been proposed for the processing of municipal solid waste into a combustible gas with the help of high-temperature pyrolysis.

To implement the project, it is necessary to build a hangar, equip it with magnet conveyor belts, crushers and fine strainer, the pyrolysis reactor, heat exchangers, condensers and gas, installation of scrubbing and a pipeline to transport gas. The total investment for construction of municipal solid waste processing plant amounts to 249755 thousand rubles.

Prospective investor is a regional operator, acting under the public-private partnership and aiming at creating infrastructure for the management of municipal solid waste.

According to the envisaged changes in the Federal legislation (Art. 1 of the Federal Law No. 89-FZ) [10], regional operators are the ones to carry out activities for the collection, transportation, processing, recycling and disposal of municipal solid waste within the territories of the Russian Federation.

Regional operators are to carry out their activities in accordance with the regional and territorial programs in the sphere of waste management [3, 4], which makes regional operators to be interested in the municipal solid waste processing and recycling.

The plant will allow to process 103920 tons of waste per year. Experts believe that one ton of waste processed with the help of high-temperature pyrolysis will generate the average of 450–500 m<sup>3</sup> of synthesis gas. To calculate the production capacity of the plant it is taken the average of 475 m<sup>3</sup>/ton of waste. Production capacity of the plant will amount to 49312 thousand m<sup>3</sup> per year.

The generated gas has the following composition (Table 3):

**Table 3.** Heat of combustion product gas

Component	Net Calorific Value, kJ / m <sup>3</sup>	Gas share, %	Heat of combustion, kJ
H <sub>2</sub>	12640	40	5056
CO	10820	17	1839.4
CH <sub>4</sub>	35850	11	3943.5
CO <sub>2</sub>	–	32	–
Total	–	100	10838.9

The calculations show that the cost of 1000 m<sup>3</sup> of gas will be 1073.9 rubles, on the whole issue – 53009.7 thousand rubles.

At the moment, the cost of 1000 m<sup>3</sup> of natural gas for wholesale buyer is about 3646 rubles.

Table 3 shows that the heat of combustion of the generated gas is 3.3 times lower than the heat of natural gas combustion. Thus, it becomes possible to calculate the market price of the product gas by the specific heat ratio. The price should not exceed 1102 rubles. The project proposes to sell gas at its cost.

Novosverdlovskaya Central Heating and Power Station is considered to become one of the consumers of the generated gas. This station has a capacity of 557 MW. The efficiency of the gas turbine generator is 65–70 %, the volume of the gas consumption is about 800 million m<sup>3</sup>



per year. These calculations are made for a constant maximum load. Though, in reality, the station consumes about 500–600 million m<sup>3</sup> per year. Therefore, it is going to be not a problem for the station to consume gas generated in the amount of approximately 49 million m<sup>3</sup>.

Part of the generated gas will be used for the needs of the plant itself. This technology involves the heating of the raw material. This requires energy, heat, which can be produced by burning the generated synthesis gas. It is expected to use about 15 % of the generated gas. Thus, about 41.957 thousand m<sup>3</sup> of gas can be sold.

Also, mechanically separated sweepings reach about 6 %, the amount of separated metal is about 4 %. Thus, the reactor is fed with about 90 % of the waste incoming to the plant. This means that the plant must process about 115466 tons of waste per year. The income sources of the project are shown in Table 4.

**Table 4.** Income of the Plant for Processing Municipal Solid Waste

The Source of Income	The amount	Price per Unit, rub.	Amount, thous. rub.
Gas distribution, thousand m <sup>3</sup>	41957	1073.9	45057.6
Sale of Ferrous Scrap, tons	4618	6000	27708.0
Payments for the disposal of municipal solid waste, tons	115466	150	17319.9
Total	–	–	90085.5

Further on, the researchers carried out feasibility study of the investment project. The project implementation period is 16 years.

Key indicators of economic efficiency of the investment project were calculated at a discount rate of 12 %, which is shown in Table 5.

**Table 5.** Key Indicators of Economic Efficiency of the Investment Project

№	Name of the Indicator	Unit	Rated Value
1	Net income	thous. rub	415380
2	Net present value	thous. rub	47668
3	Discounted payback period	years	10.9
4	Index of profitability investment	–	1.19
5	Maximum cash outflow	thous. rub	220000
6	Internal return rate	%	15.95
7	Break-even point	thous. m <sup>3</sup> of gas	18621
8	Financial safety margin	%	55.6

The analysis of the indicators of economic efficiency of the project proves that the project of the construction of the plan for the processing of municipal solid waste with the help of high-temperature pyrolysis is attractive and appropriate for implementation. The main environmental benefit of the project is the recycling of accumulated and newly generated waste. It helps to prevent the accumulated environmental damage and prevent damage to the environment. Though payback period of this investment is large enough, we can confidently talk about the need to invest in the future in terms of achievements of the current and deferred environmental impact for the future generations.

## 5. Conclusion

As a result, the implementation of the research leads to the following conclusions, which are crucial to justify the choice of technology for the processing of municipal solid waste.

1. At present, there are several technologies of municipal solid waste utilization excluding the process of direct incineration. In each case, the technology is determined in accordance with local conditions and requirements. As for the municipal entity of Ekaterinburg the researchers have not determined any universal analogue, fully consistent with the existing conditions terms (municipal solid waste composition, sorting and processing line, capacity, tariffs, etc.).

2. The high-temperature pyrolysis technology is technically feasible and can be considered as industrial for the municipal solid waste in the city of Ekaterinburg.

3. The technical efficiency of the pyrolysis technology in the first place depends on the morphological composition of municipal solid waste, which is determined by several organizational and social factors: the level of living standards, waste collection and transportation system as well as other factors to be examined.

4. The syngas generated in the pyrolysis process may have a calorie, which is about three times lower than that of calorific gas.

5. The synthesis gas pyrolysis can be considered as a substitute fuel for several energy and processing plants running on gas.

6. The project will reduce the load of municipal solid waste landfills. It will help to recycle about 10 % of the municipal solid waste generated in the city of Ekaterinburg and to improve the environment. Moreover, the project corresponds with the Integrated Strategy for Municipal Solid Waste Management within the territory of Sverdlovsk region up to 2030.

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